Broad-band spectral characterization of plasma based sources of soft X-ray and VUV radiation

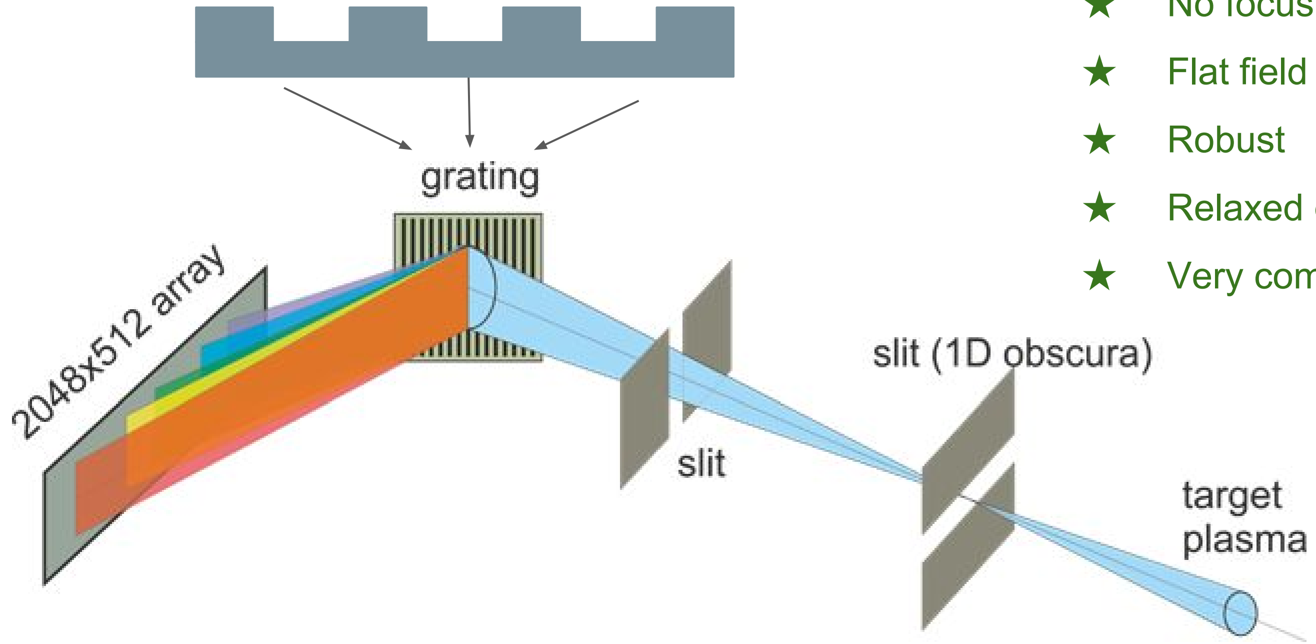
2017 Source workshop, Nov. 6-8, Dublin, Ireland

Applications = motivation

- Search for efficient plasma-based sources of VUV radiation
- High-harmonic generation
- In-band vs out-of-band emission measurements for EUVL sources

1. BROADBAND SPECTROSCOPY

AGS = amplitude grating spectrometer



Important features:

★ No focusing elements

★ Flat field

★ Robust

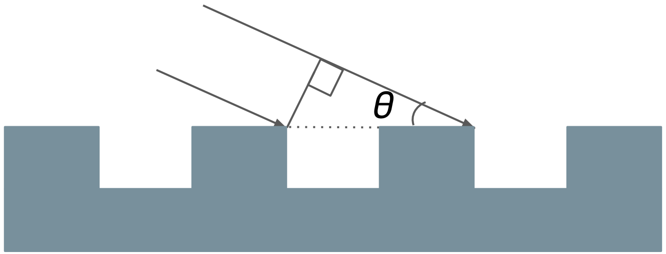
★ Relaxed grating specs

★ Very compact

Advantages of the grazing incidence (GI) operation

1

Effective period reduction: $d_{eff} = d \sin\theta$

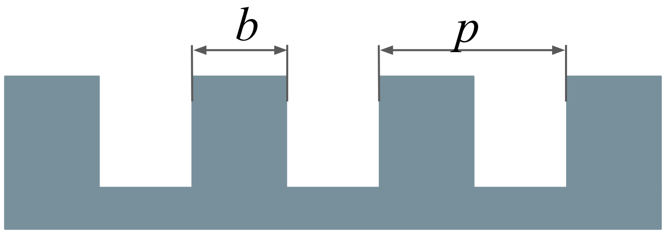


~100-1000 l/mm gratings can be used

2

GI illumination with a confined beam -> large number of grating periods in the diffraction, increases resolution

Diffraction orders



$$b = f\,p$$

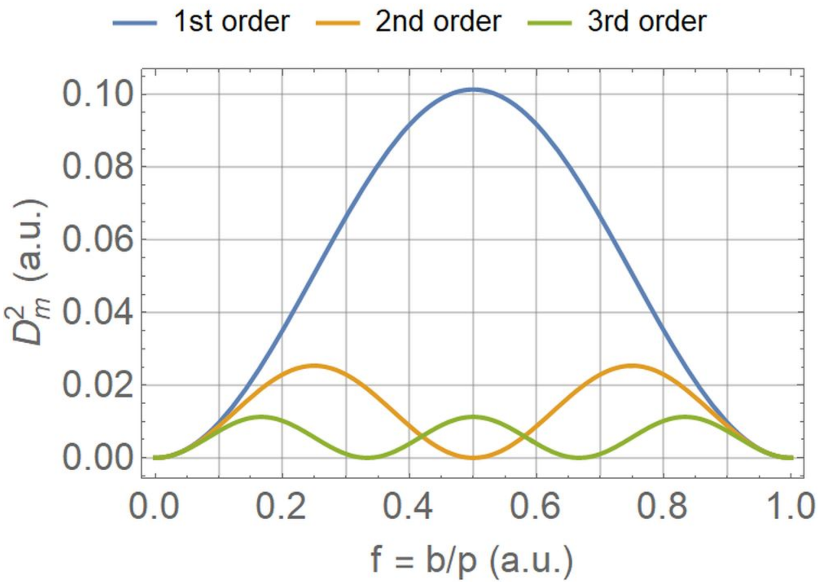
Deep grooves - light reflected only from top surface

Diffraction efficiencies predicted by scalar diffraction:

$$I_m = I_{inc} D_m{}^2 R_m$$

$$D_m = f\,\mathrm{sinc}(\pi m f)$$

for details see: JOSA 45(9), 756 (1955)



even orders suppressed when f = 0.5

Handbook diffraction principles

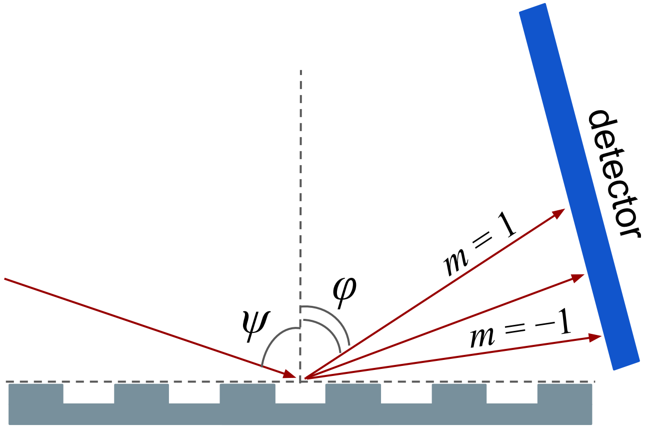
Main gratin equation:

$$\sin\psi + \sin\varphi = m\lambda/p$$

Angular dispersion:

$$D = d\varphi/d\lambda = m/(p{\cdot}\cos\varphi)$$

D significantly increases at φ → 90°



Implementation

View of device with Hamamatsu CCD detector

SPECIFICATIONS:

Grating period	3 μm
Grazing angle	6 deg
Slit width	80 μm
Spectral region	6-200 nm
Resolution, $\lambda/\delta\lambda$	up to 50
Detector	CCD*

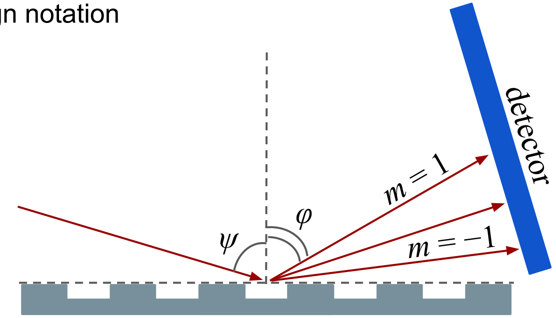
*CCD options
line Toshiba 1304AP, 3600 8 μm pixels
array Hamamatsu S7030/S7031, 1024x122 24 μm pixels
array ANDOR DX440-BN, 2048x512 13.5 μm pixels

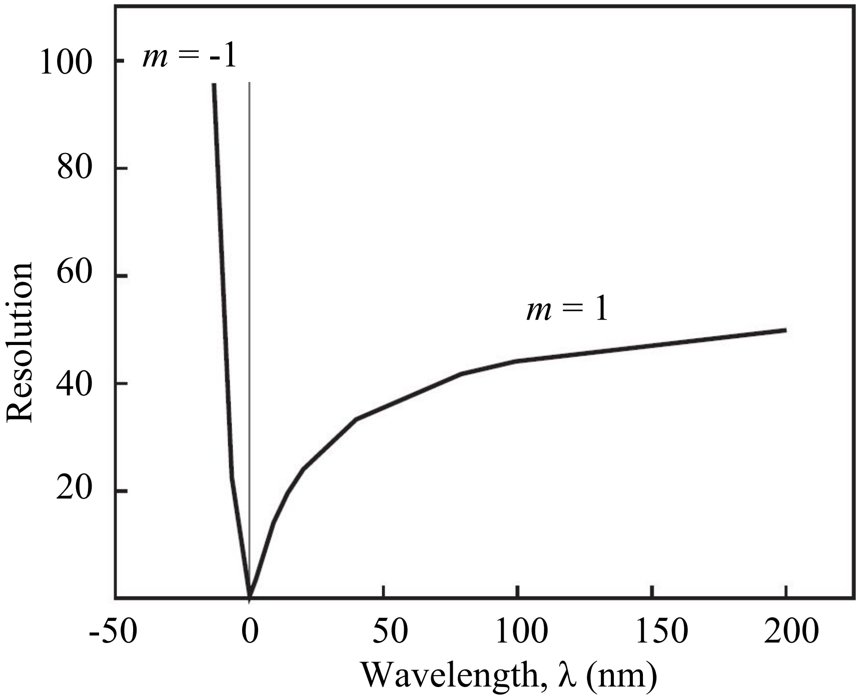
Spectral resolution

Calculated for the given hardware configuration (see prev. slide) + using typical values:

Source - spectrometer distance 0.5 - 1 m
Source size 0.1 - 1 mm

reminder for order sign notation





Quantum Electronics, 2017, **47**:9, 853–859

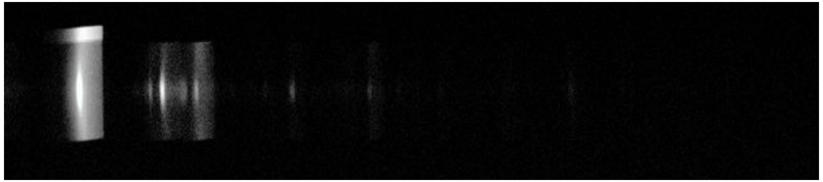
Wavelength calibration

Radiation source: laser-produced plasma with light (low-Z) target materials (LiD, Be, C,...)

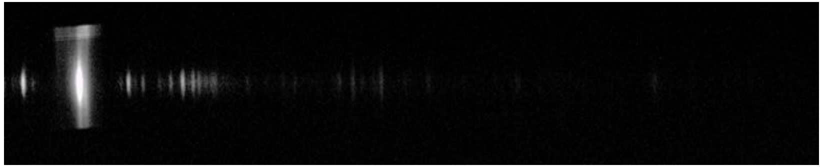
Registration system: Back-side illuminated CCD camera ANDOR DX440-BN

NIST tabulated data for optical transitions of light elements is used for the wavelength calibration

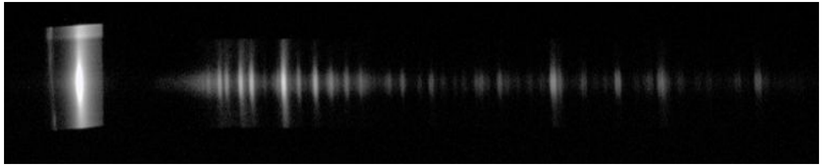
LiD



Be



C



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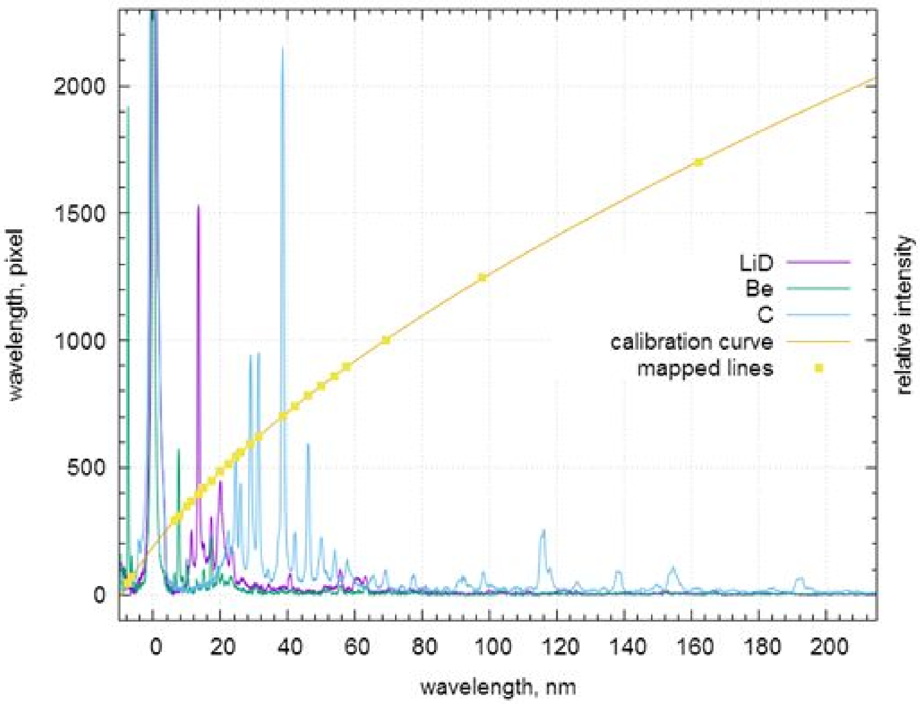
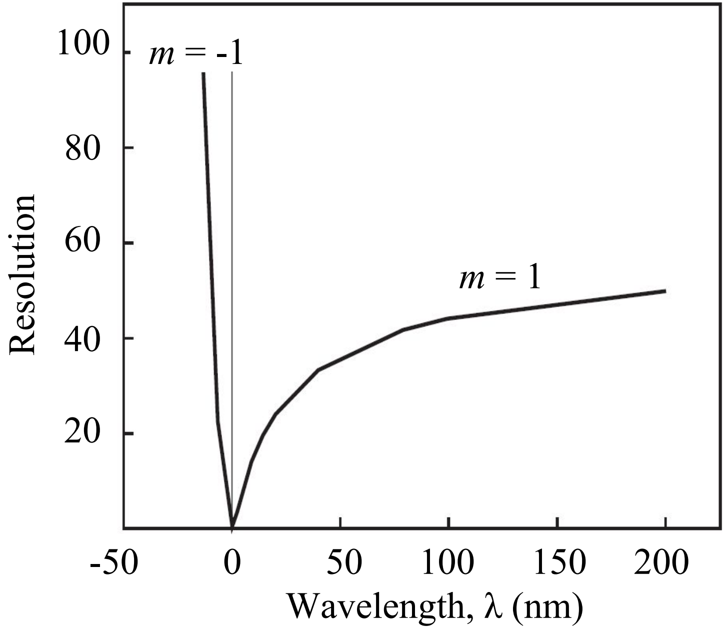
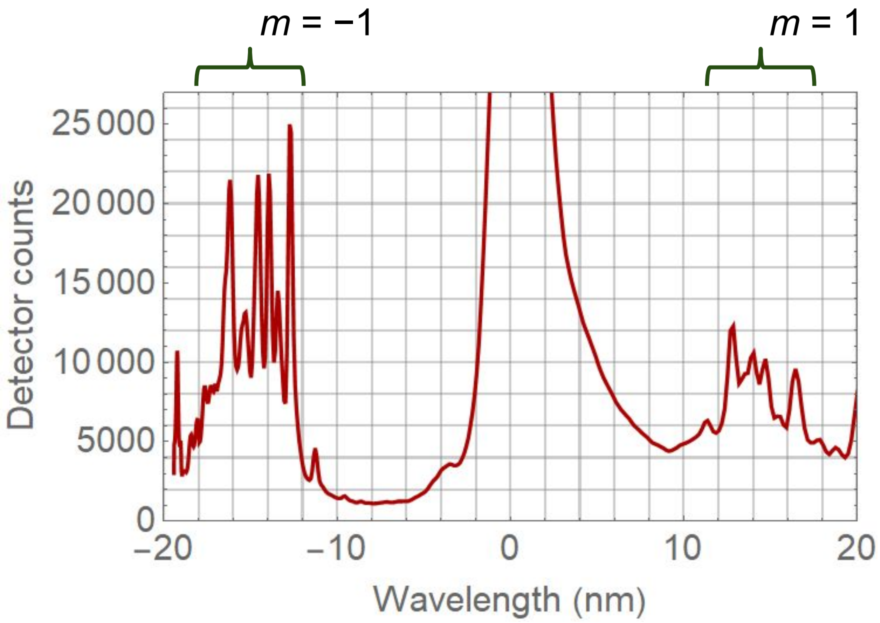


High resolution and moderate resolution

Comparison between +1 and -1 orders of diffraction

Radiation source: laser-produced plasma with LiF target



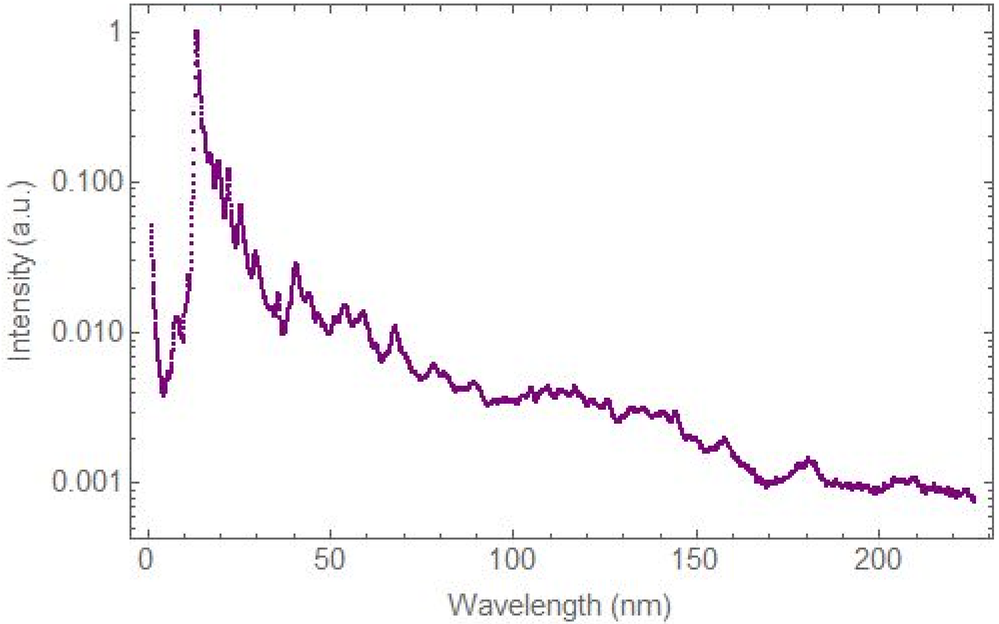


evidently, “$m = -1$” lines are better resolved

Contribution of high diffraction orders

Radiation source: laser-produced plasma with Sn target

Registration system: Back-side illuminated CCD camera ANDOR DX440-BN



Major contribution is due to the main Sn peak at 13.5 nm

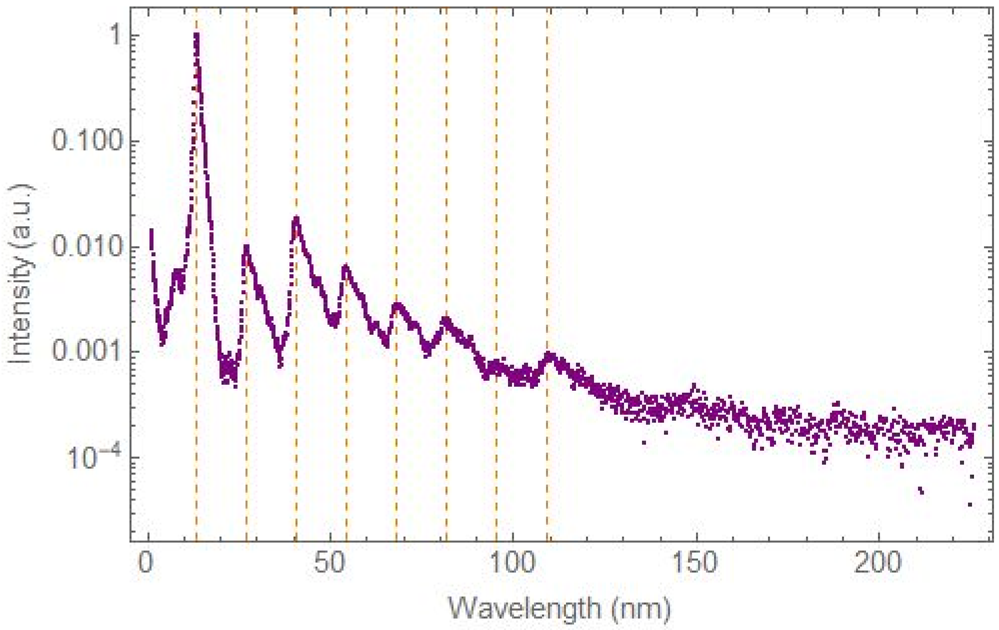
Contribution of high diffraction orders

Radiation source: laser-produced plasma with Sn target

Registration system: Back-side illuminated CCD camera ANDOR DX440-BN

+Spectral filter: free-standing Zr/Si multilayer with bandpass centered at 13.5 nm

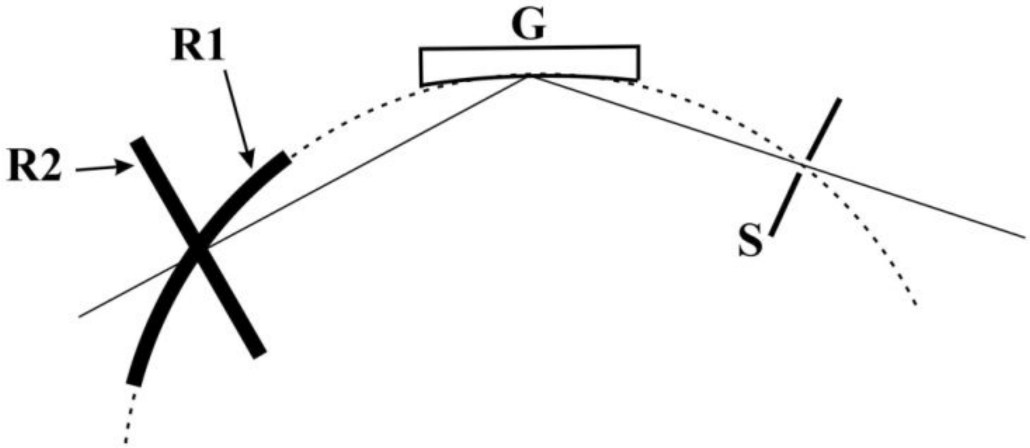
1st 2nd 3rd 4th 5th 6th 7th 8th diffraction orders



Diffraction efficiencies can be estimated for further spectral postprocessing

2. HIGH-RESOLUTION SPECTROSCOPY

Rowland and off-Rowland: how it usually works

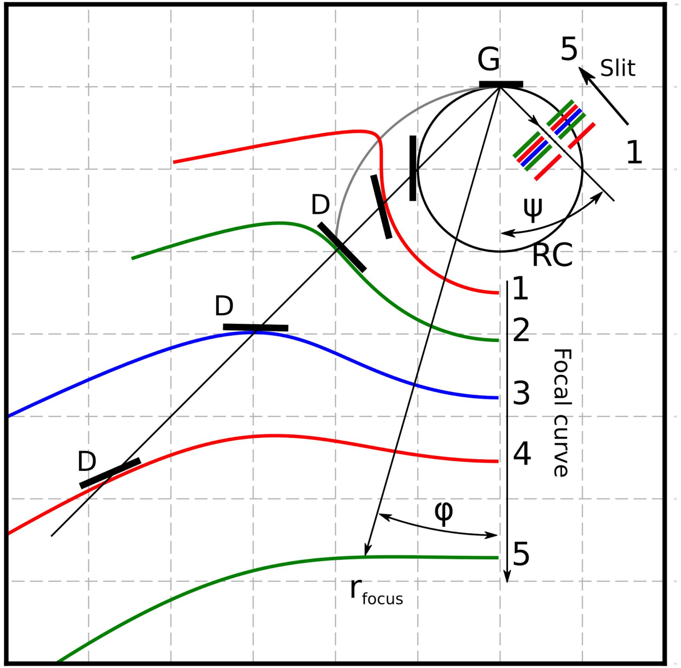


R1 = Rowland - detector has to bended
 -> not compatible with standard CCD

R2 = off-Rowland - detector is out of the focal plane
-> high resolution achieved only at around the focal spot

What if we shift the entrance slit?

Transformation of the focal curve vs slit position



G - grating; D - detector; RC - Rowland circle

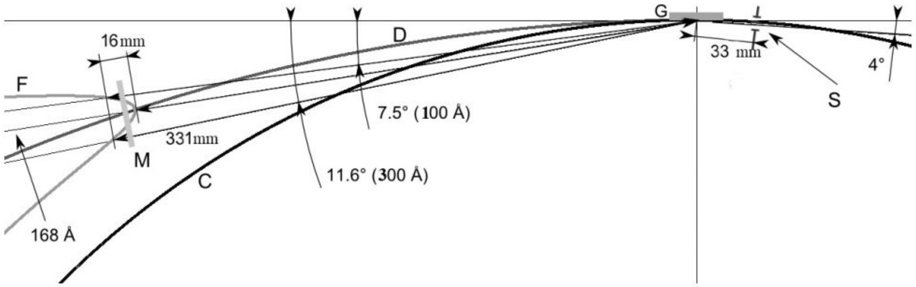
It is possible to design optical scheme with nearly flat field perpendicular illumination of the detector

Old idea revision - see W. Baily, Philisophical Mag. Ser. 5 **15**, 183 (1883).

Implementation for grazing incidence

Test experimental configuration:

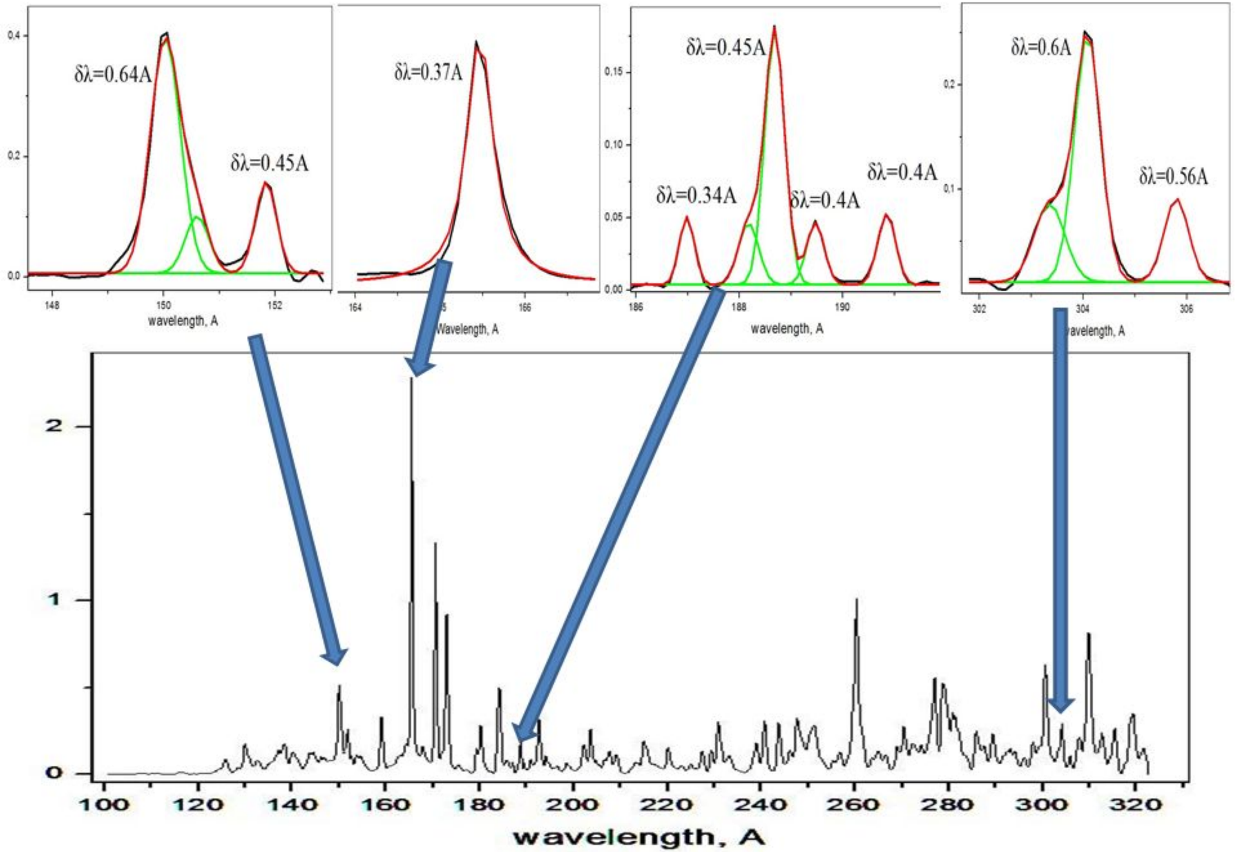
Line density	600, 1200 l/mm
Grating radius of curvature	1 m
Working size of the grating	6 mm
Entrance slit width	10 µm
Angle of incidence	4 deg
Slit-grating distance	33 mm
Detector-grating distance	320 mm
Diffraction order	1st



Experimental results

Radiation source:
discharge in argon

Registration system:
Back-side illuminated
CCD camera ANDOR
DX440-BN



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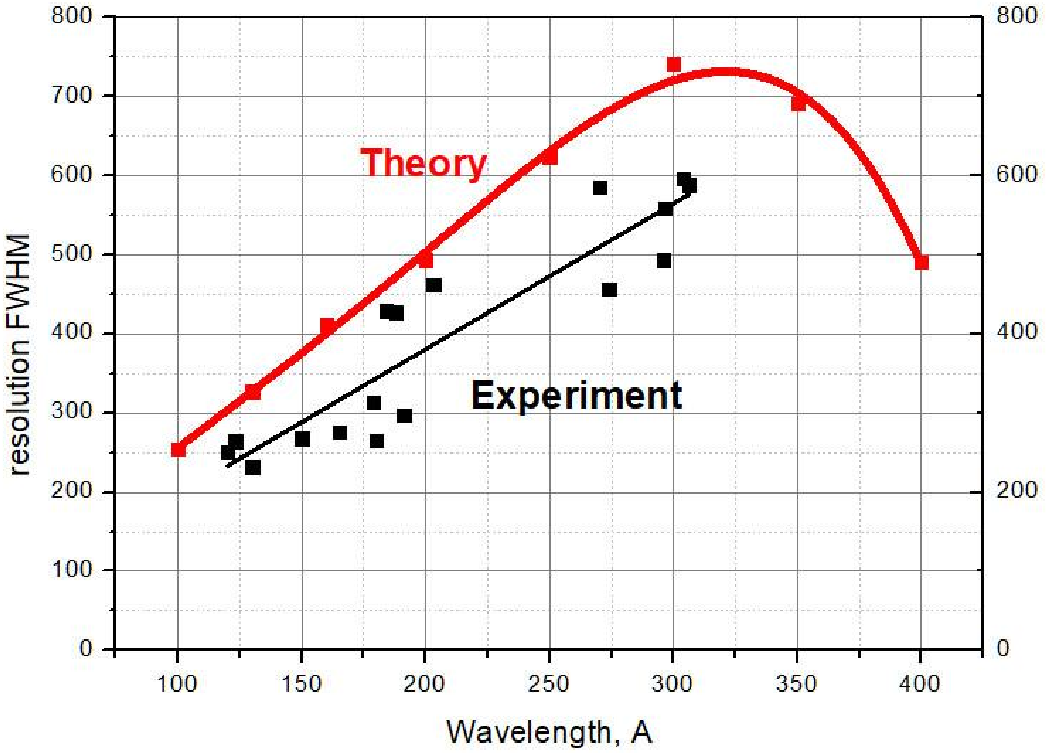

Summary

- Developed compact grazing-incidence spectrometer for broadband SXR-VUV spectral measurements
    - Spectral range 5-200 nm
    - Spectral resolution up to 50 in the range in 1st diffraction order
    - Spectral resolution up to 100 in the range in -1st diffraction order (but limited spectral range)
- Developed grazing-incidence spectrometer for high resolution measurements in EUV range
    - Spectral range 10-40 nm
    - Spectral resolution up to 600
- For more metrology solutions see www.isteq.nl

Contributing authors

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